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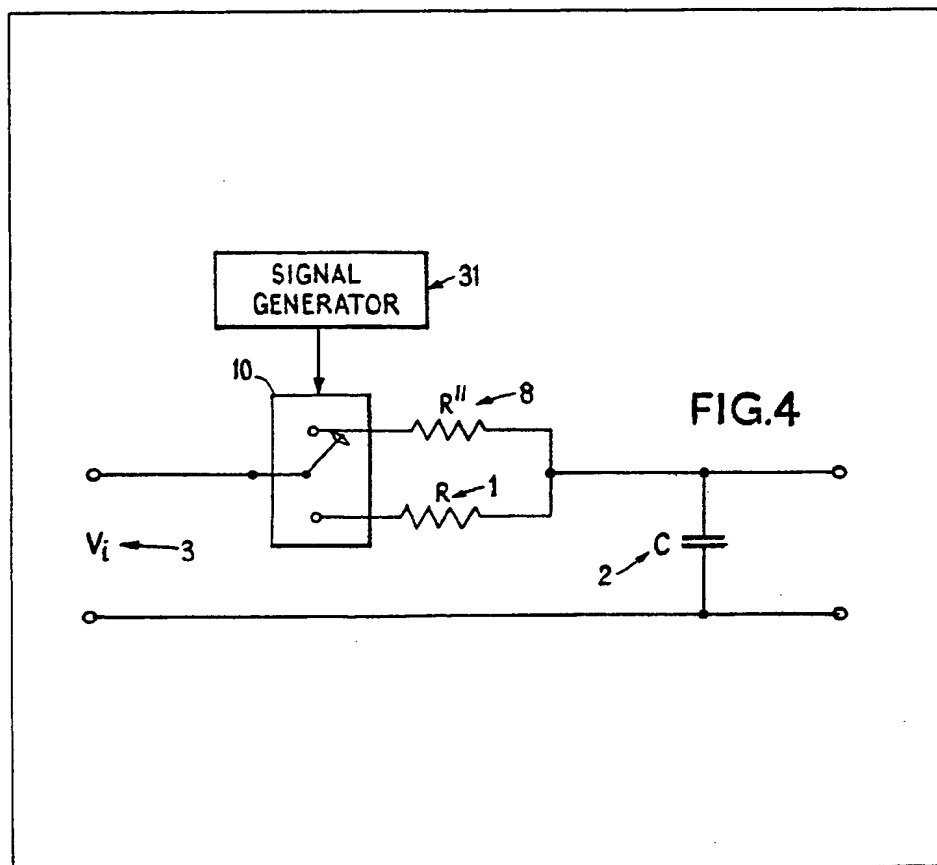
(54) Commutated resistor circuit

(57) A variable electrical resistance circuit including a network of interconnected resistors ( $R, R'$ ) and one or more analogue switches (5), for switching the resistor interconnections, controlled by a variable mark/space ratio control signal so as to provide a continuously variable intermediate value of circuit resistance.

The control means may include a signal generator for generating a variable mark space ratio square wave voltage switching signal and the switches may include at least one dual path switch such that a first path is accessed when the switching signal is high and the second path is accessed when the signal is low.

The circuit may include in a low pass filter such that the switching

signal has a frequency which is high relative to the cut-off frequency of the filter. The invention may also be applied to a bandpass filter.



The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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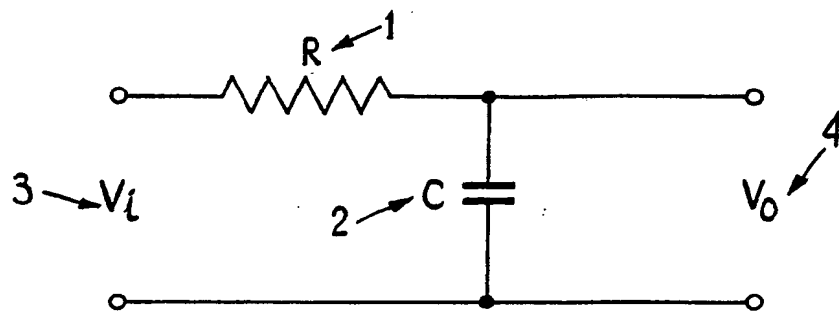


FIG. 1

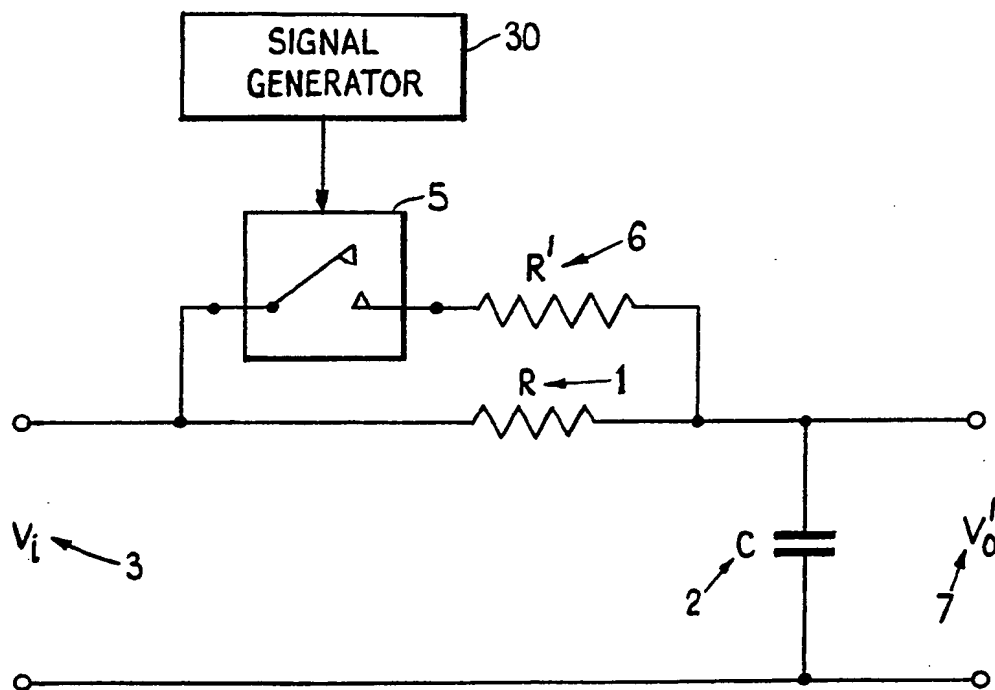
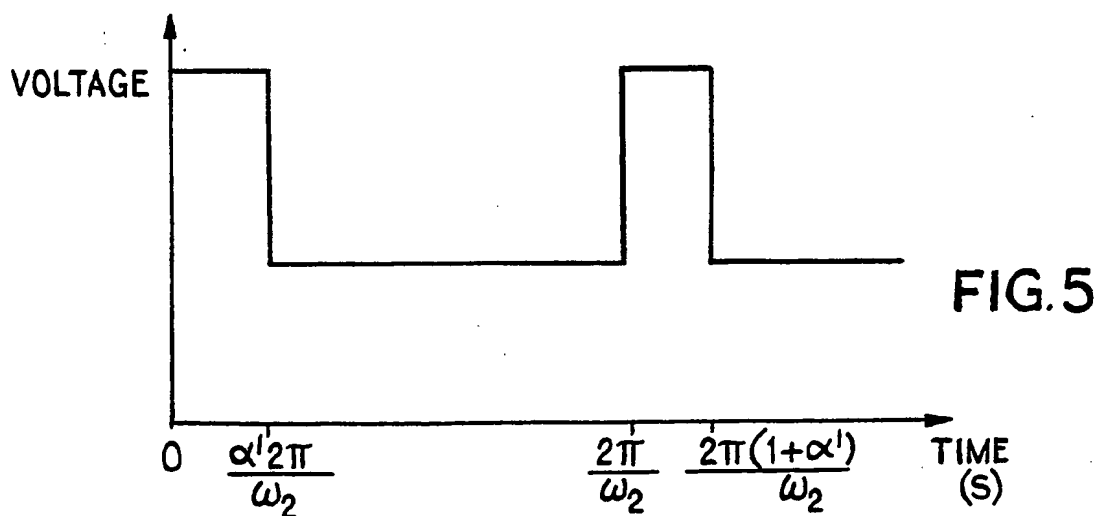
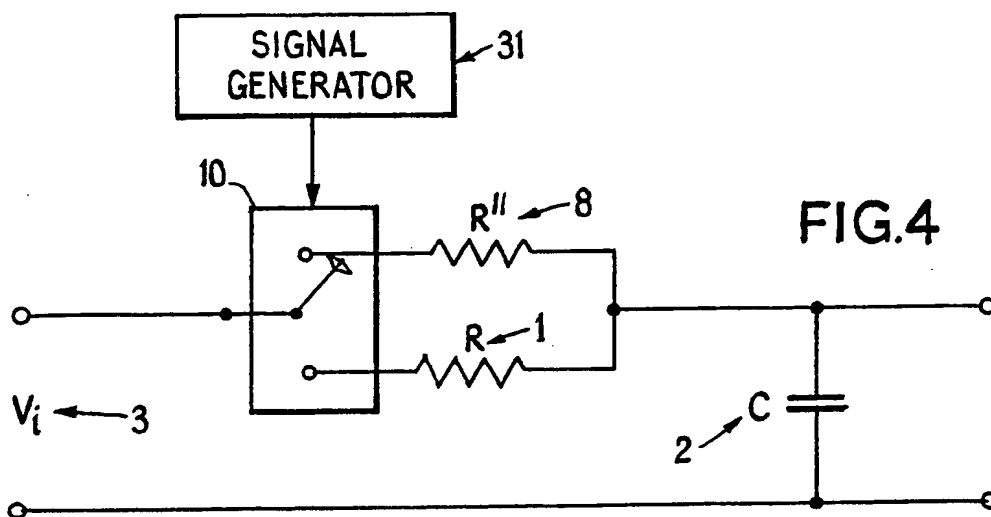
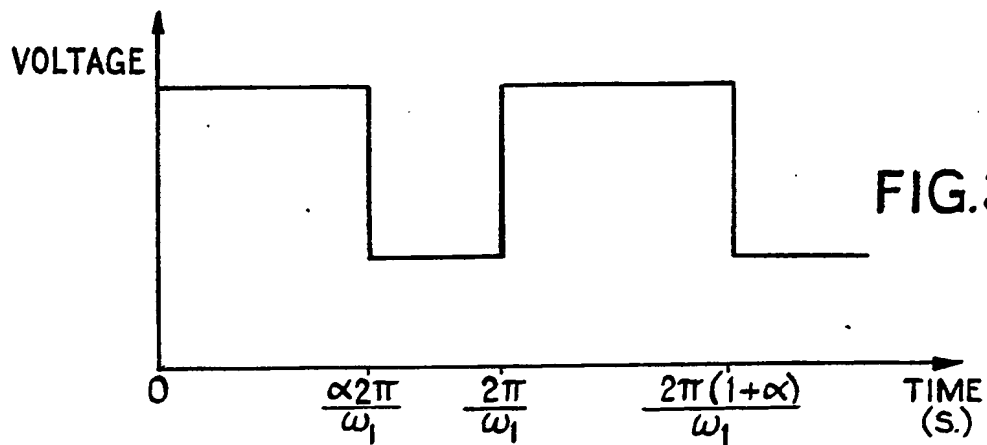


FIG. 2

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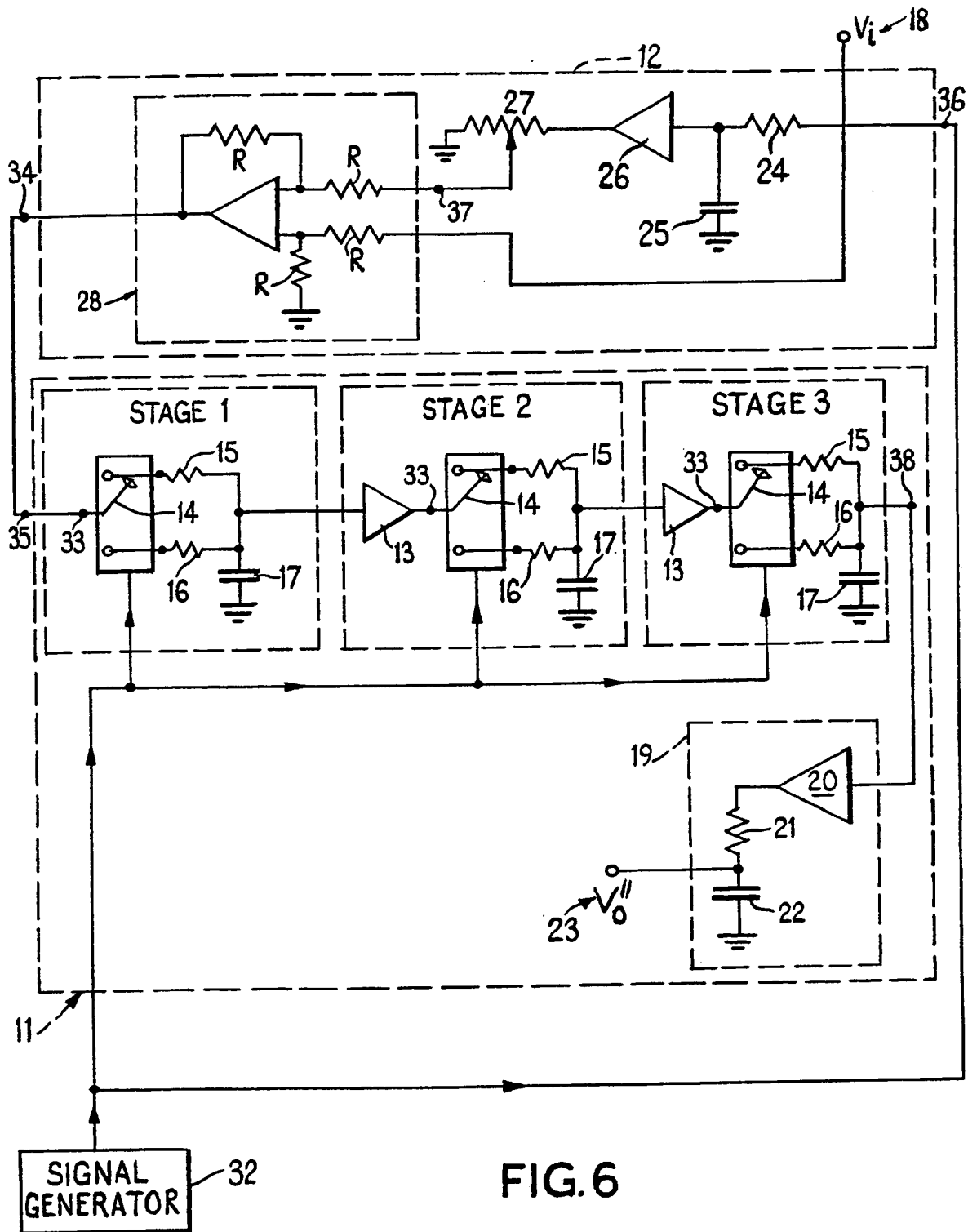


FIG. 6

## SPECIFICATION

**Improvements in or relating to variable electrical resistance circuits**

5 The invention concerns improvements in or relating to variable electrical resistance circuits and particularly, but not exclusively to the control of values of resistance in an electronic filter in order to control the cut-off frequency of the filter.

10 The characteristics of a filter are determined by the parameters of its component electronic devices. For example values of resistance, capacitance and amplifier gain will determine the characteristics of a particular filter circuit.

15 A conventional method of changing the characteristics of a filter is to disconnect a component device and connect in its place a second device having parameters different from those of the first device. An example involves the use of a simple low pass filter consisting of a resistance, R, in series with a capacitor, C. An output is taken at the terminals of the capacitor, the input completing a series circuit with the resistance and the capacitance. The cut-off frequency,  $w_o$ , of this filter (the frequency at which the output voltage is  $1/\sqrt{2}$  times the low frequency output voltage) is given by the relation

$$w_o = \frac{1}{RC}$$

35  $w_o$  may therefore be changed by changing the value of R in the circuit. Conventionally this is achieved by connecting in another resistance, R' for instance, and bypassing R to give another cut-off frequency,  $w_o'$  such that

$$w_o' = \frac{1}{R'C}$$

45 In order to provide a selection of cut-off frequencies a plurality of resistance values are provided, the appropriate resistance being switched into the circuit to give the required cut-off frequency.

50 An aim of the invention is to provide a continuously variable value of resistance using a number of fixed resistors, the variable value being controllable by digital circuitry.

55 According to the present invention there is provided a variable electrical resistance circuit including:

60 a network of interconnected resistors, one or more analogue switches for varying the resistor interconnections, each having a plurality of switch paths accessible for a continuously variable duration of time,

65 a control means for controlling the relative durations of time for which each switch accesses each path so as to provide a continu-

ously variable intermediate value of resistance.

70 The network of resistances and the switch or switches may be arranged to provide resistors connected in either series or parallel or both.

75 The analogue switch or switches may be solid state switches and the control means is preferably adapted to control the switches so as to vary the resistor interconnections at high frequency.

80 The analogue switch or switches may comprise a dual-path switch and the control means may comprise a signal generator which generates a variable mark space ratio square wave voltage switching signal so that one path is accessed for the duration of time for which the signal is at a high voltage and the second path is accessed for the duration of time for which the signal is at a low voltage.

85 The circuit may further include capacitive reactance and comprise a filter, the cut-off frequency of which is determined by the value of the intermediate resistance.

90 Preferably, the filter is a low pass filter such that the switches are continually switched between switch paths with a frequency much higher than the cut-off frequency of the filter.

95 The invention may be applied to a band-pass filter, the low frequency cut-off being determined by the value of a first intermediate resistance and the high frequency cut-off being determined by the value of a second intermediate resistance. Precise control of the band-pass is therefore possible. By providing a very narrow band-pass, the invention may be applied to an oscillator, the resonant frequency of which is controlled by the first and second values of intermediate resistances.

105 Another application of the invention is to spectral analysis, the frequency of analysis being the resonant frequency controlled by the first and second resistances.

110 Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings of which

*Figure 1* is a circuit diagram of a simple, conventional low-pass filter with input and output voltages shown.

115 *Figure 2* is a circuit diagram of the simple low-pass filter of Fig. 1 adapted in a first way according to the invention.

*Figure 3* is a graph describing a control, square wave voltage switching signal for application to the circuit of Fig. 2.

120 *Figure 4* is a circuit diagram of the simple low-pass filter of Fig. 1 adapted in a second way according to the invention.

*Figure 5* is a graph describing a control, square wave voltage switching signal for application to the circuit of Fig. 4.

125 *Figure 6* is a circuit diagram of a 18 dB per octave roll-off anti-aliasing filter for one channel of a multi-channel analogue interface system for a computer.

In Fig. 1, a simple, conventional low-pass filter consists of a resistance, 1, having a value  $R$ , in series with a capacitance, 2, having a value  $C$ . A sinusoidally alternating input voltage, 3, having a value  $V_i$  in a frequency of  $\omega$  rad  $s^{-1}$  is applied across the resistance and capacitance and an output voltage, 4, with value  $V_o$  is taken from across the capacitance, 2.

The behaviour of the circuit is described by the equation

$$\left| \frac{V_o}{V_i} \right| = \frac{1}{\sqrt{(1 + \omega^2 C^2 R^2)}}$$

Thus, the filter has a cut-off frequency,  $\omega_c$ , such that

$$\left| \frac{V_o}{V_i} \right| = \frac{1}{\sqrt{2}}$$

for

$$\omega_c = \frac{1}{RC}$$

In Fig. 2 a simple low-pass filter according to the invention consists of the resistance, 1, of value  $R$ , the capacitance, 2, of value  $C$  and the input voltage, 3, of value  $V_i$  in series as in Fig. 1 and, in addition, includes a resistance, 6, of value  $R'$  connected in parallel with resistance 1, and a switch, 5, which is under the control of a signal generator, 30 which uses digital circuitry. An output voltage, 7, of value  $V_o$  is taken from across the capacitor.

Switch 5 can be either open so that  $R'$  is not connected into the circuit or closed so that  $R'$  is connected into the circuit in parallel with  $R$ . A control, square wave voltage switching signal as shown in Fig. 3, from the signal generator controls the conduction path through the switch by opening and closing the switch with a repetition frequency of  $\omega_1$ , where

$$\omega_1 \gg \omega_c$$

The switch signal of Fig. 3 is such that from time 0 to time  $\alpha 2\pi/\omega_1$  the signal takes on a high voltage and from time  $\alpha 2\pi/\omega_1$  to time  $2\pi/\omega_1$  the signal takes on a low voltage, where the value of  $\alpha$  is under the control of the signal generator and  $\alpha \leq 1$ . The mark space ratio of the signal is therefore  $\alpha/1-\alpha$ .

The control switching signal acts upon the switch, 5, so that from time 0 to time  $\alpha 2\pi/\omega_1$  the switch is closed and the filter has a resistive component of  $RR'/R + R'$  and from time  $\pi 2/\omega_1$  to time  $2\pi/\omega_1$  the switch is open and the filter has a resistive component of  $R$ .

For  $\alpha = 0$  the resistive component is  $R$

permanently and the filter therefore has a cut-off frequency,  $\omega'_c$ , such that

$$\omega'_c = \frac{1}{RC}$$

For  $\alpha = 1$  the resistive component is  $RR'/R + R'$  permanently and so the filter has a cut-off frequency such that

$$\omega'_c = \left( \frac{RR'}{R + R'} \right) C$$

Thus, by varying the mark space ratio,  $\alpha/1 - \alpha$  of the control signal the control means is able to vary the cut-off frequency,  $\omega'_c$ , of the filter between a value of  $1/RC$  and of

$$\frac{1}{(RR'/R + R')C}$$

by means of digital logic.

In Fig. 4 a resistance, 8, of value  $R''$  a signal generator, 31, and a switch, 10, have been added to the filter circuit of Fig. 1, the switch, 10, having two switch paths; a first in which resistance 8 and not resistance 1 is connected into the circuit, and a second in which resistance 1 and not resistance 8 is connected into the circuit.

A signal as depicted in the graph of Fig. 5 is applied by the signal generator, 31, to switch 8 such that from time 0 to time  $\alpha' 2\pi/\omega_2$  the switch conducts via the first path and from time  $\alpha' 2\pi/\omega_2$  to time  $2\pi/\omega_2$  the switch conducts via the second path. Thus for  $\alpha' = 0$  the filter has a cut-off frequency,  $\omega''_c$ , of  $1/RC$  and for  $\alpha' = 1$  the filter has a cut-off frequency of  $1/R''C$ . As the mark space ratio,  $\alpha'/1 - \alpha'$ , of the signal varies,  $\omega''_c$  therefore varies between  $1/RC$  and  $1/R''C$ .

In Fig. 6 an anti-aliasing filter having a cut-off frequency  $\omega'''_c$  consists of a filter section, 11, which includes three stages; Stage 1, Stage 2 and Stage 3 connected in tandem, an offset section, 12, and a signal generator, 32.

Stages 2 and 3 consist of an operational amplifier, 13, of type LM 310 (unity gain) with an output connected to an input, 33, of a switch, 14, of type AD 7512 DIKN which has two possible switch paths; a first in which a  $100 \text{ k}\Omega$  resistance, 15, and not a  $12 \text{ k}\Omega$  resistance, 16, is connected to the input, 33, and a second in which resistance 16 and not resistance 15 is connected to the input 33.

Stage 1 consists of the same components as Stages 2 and 3 except that Stage 1 does not include an amplifier, 13.

A signal generator, 32, controls the switch

status of each of the three switches, 14, in the three stages such that the status of each one of the switches is the same as the status of the other two.

5 0.01  $\mu$ F capacitors, 17, connect the switch paths of switches 14 in each of Stages 1 to 3 to earth via either resistances 15 or resistances 16 according to the condition of switches 14.

10 An input voltage, 18, which is limited to  $\pm 3$  Volt peak-to-peak is input to an amplifier stage, 28, incorporated in the offset section, 12. An output, 34, of the amplifier stage, 28, is connected to an input, 35, of the filter section, 11, the input, 35, being connected to the switch input, 33, of Stage 1.

An output, 38 of Stage 3 is connected to a low-pass output stage, 19, consisting of an amplifier, 20, of type LM 310 having an output connected to earth via a resistance, 21, of value 100 k $\Omega$  in series with a capacitance, 22, of value 0.1 nF. An output voltage, 23, of value  $V_o$  is then taken across the capacitance, 22.

25 The signal generator applies TTL in order to output a square wave voltage switching signal of frequency 100 kHz and of variable mark space ratio which can be set by a user of the filter. The signal generator controls the switches, 14, such that, when the square wave switching signal is at a high voltage, resistances 15 are connected to the inputs, 33, of switches 14 and when the square wave switching signal is at a low voltage, resistances 16 are connected to the inputs, 33, of switches 14. Thus, resistances 15 and 16 are continually switched and out of the filter at a frequency of 100 kHz so that the effective resistance supplied to the filter takes on a value lying between the value of 15 and that of 16, the particular value depending upon the mark space ratio of the signal set by the user. The cut-off frequency,  $W_o$  of the filter is therefore variable by varying the value of switching signal mark space ratio which, in turn, is under the control of TTL.

In practice the input to the filter constitutes an ac signal and this is superimposed upon a dc level.

50 It has been found experimentally that the dc level changes according to the frequency of the square wave voltage switching signal output by the signal generator. The function of the offset section, 12, is to offset this dc level change.

The same square wave voltage switching signal which is output from the signal generator is applied to an input, 36, of the offset section. The signal is first applied to a smoothing unit consisting of a 10k $\Omega$  resistance, 24, in series with 0.01  $\mu$ F capacitance, 25, with an amplifier, 26, of type LM 310, connected to take an input from across the capacitance, 25. The op-amp output is fed to a potentiometer, 27, the output of which is

fed to an input, 37, of the amplifier stage, 28. The output, 34, of the amplifier stage, 28, is then fed to the input, 35, of the filter section, 11. The dc offset is therefore controlled by the potentiometer, 27.

In practice, switching noise is produced in the filter by the switches, 14. This is minimised at the filter section output, 23, by the low-pass output arrangement of resistance 21 and capacitance 22 which has a cut-off frequency at approximately 10kHz. This is sufficiently high to exceed the cut-off of Stages 1 to 3 of the filter (approximately 1 kHz) but sufficiently low to cut out switching noise around 100 kHz.

If the invention is applied to other channels of the multichannel interface system, close tracking between the channels is possible.

The invention is not confined to the details outlined in the above embodiments and variations within the cope of the invention will be apparent to those skilled in the art.

The anti-aliasing filter described above may be varied, for instance by applying a square wave switch signal at a frequency other than 100 kHz. Switch noise is, however, more difficult to remove at the filter section output as the switch signal frequency approaches the cut-off frequency of the filter. A second variation would be to replace one of the resistances 15 or 16 by an open circuit. Another variation would be to have a larger number of resistance than the two resistances, 15 and 16, for switching to or to have more than one signal generator controlling the switches, each being independently variable.

#### CLAIMS

1. A variable electrical resistance circuit including a network of interconnected resistors, one or more analogue switches for switching the resistor interconnections, each having a plurality of switch paths accessible for a continuously variable duration of time, and control means for controlling the relative durations of time for which each switch accesses each path so as to provide a continuously variable intermediate value of circuit resistance.

2. A variable electrical resistance circuit as claimed in claim 1 wherein the control means includes a signal generator for generating a variable mark space ratio square wave voltage switching signal and wherein the analogue switch or switches include(s) at least one dual path switch such that one path is accessed for the duration of time for which the switching signal is at a high voltage and the second path is accessed for the duration of time for which the signal is at a low voltage.

3. A variable electrical resistance circuit as claimed in claim 2 wherein the circuit is included in a filter having a cut-off frequency the value of which is determined by the intermediate value of resistance.

4. A variable electrical resistance circuit as claimed in claim 3 wherein the filter is a low-pass filter and the square wave switching signal has a high frequency relative to the cut-off frequency of the filter.

5. A band-pass filter having a low and a high cut-off frequency and including two variable electrical resistance circuits according to either of claims 1 or 2 wherein the variable intermediate value of resistance of one circuit determines the value of the low cut-off frequency and the variable intermediate value of resistance of the other circuit determines the value of the high cut-off frequency.

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